

Intelligent Tutors: Past, Present and Future

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National Science Foundation



Outside of the School House

Soldiers learn with:

Twitch speed vs. conventional speed

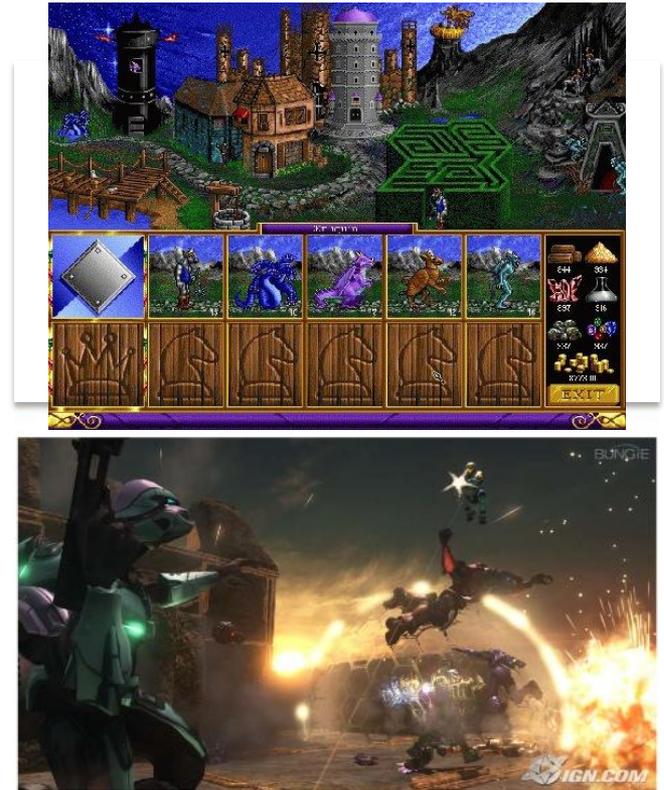
Parallel vs. linear processing

Graphics-based vs. text-based

Connected vs. stand-alone

Active vs. passive

Fantasy vs. reality



No wonder school houses are boring!

Training in the School House is Expensive and Boring

Information is instantly available.

Change is constant and rapid.

Distance and time do not matter.

Powerful tools are taken for granted.

Multimedia entertainment is omnipresent

Multi-tasking is how people work

(not not effectively).

No wonder soldiers are bored in school houses !



U.S. Report Card

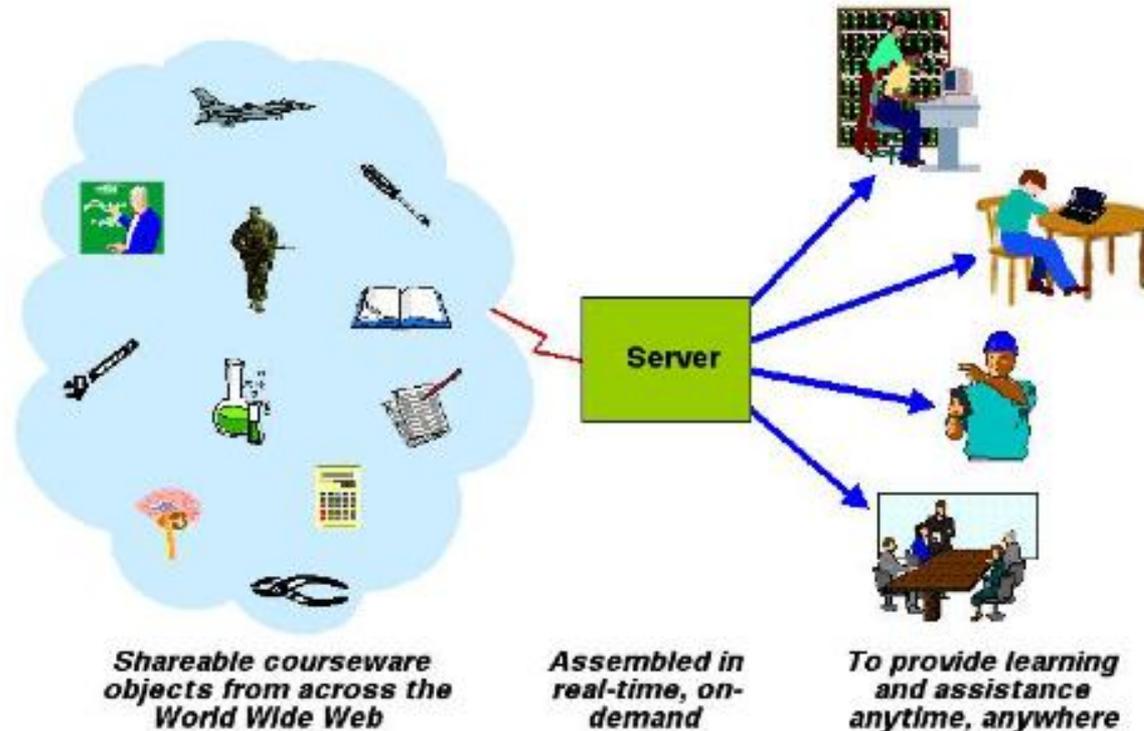
The U.S. has slipped behind in the K-12 classroom.

- Only 30% of 8th graders and 21% of 12th graders scored proficient or higher in science (National Assessment of Educational Progress exams).
- The U.S. ranked 14th in reading, 17th in science and 25th in math (Program for International Student Assessment).
- Only 75% of high school students graduate, below the average (organization for Economic Co-operation and Development).
- U.S. has relinquished its lead and fallen to 9th in the production of young people with a college degree.

Past, Present and Future

Future, Past, and Present

VISION: GLOBAL LEARNING GRID



Wisher & Fletcher, 2004

Asynchronous, continuous learning, provided anytime, anywhere through a learning repository that provides real-time, seamless, ubiquitous training and assessment. The big need is for intelligent, instructional content.

The Motivation

Improved teaching:

2 Sigma for human one-on-one tutoring

.50 Sigma for interactive multimedia,
(raises the median score from 50% to 69%)

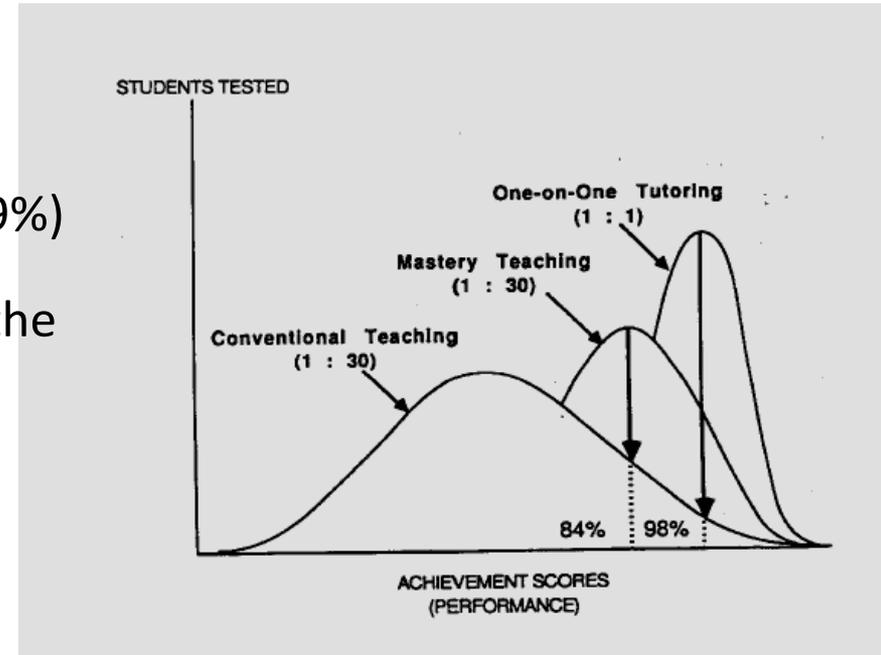
1.05 Sigma for intelligent tutors (raises the median score from 50% to 85%).

Reduced Cost:

~63% less less expense to provide instruction with technology.

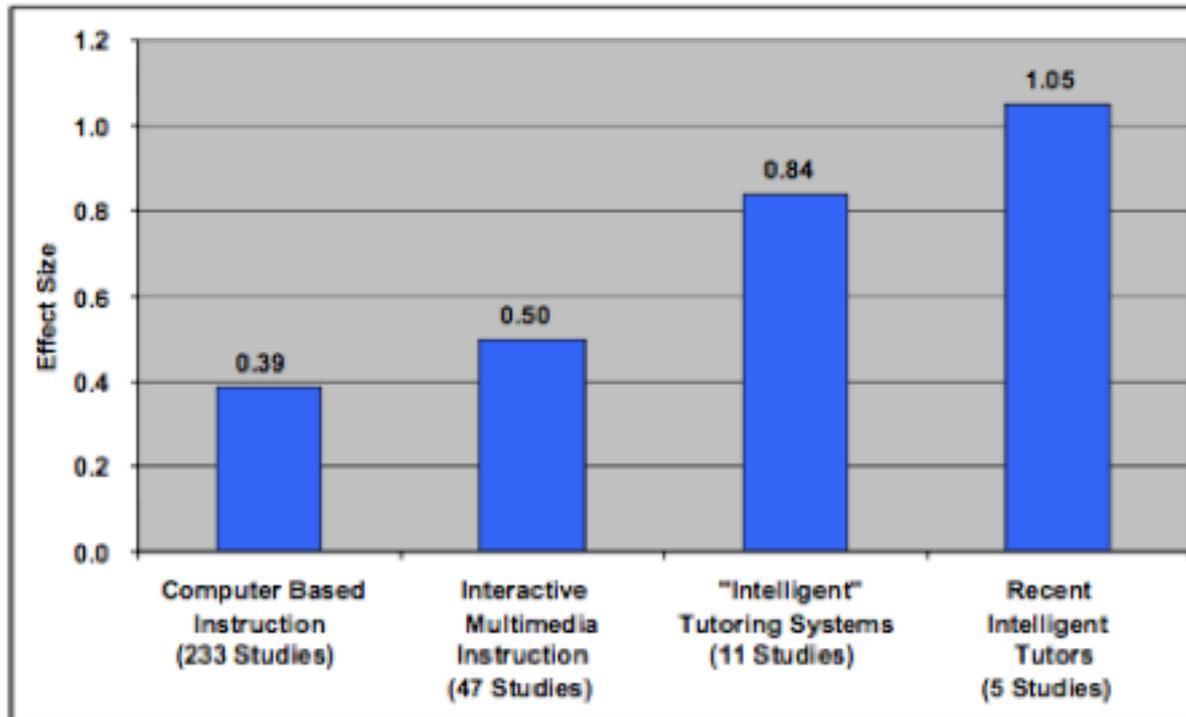
Improved cost-efficiency:

Bring instruction to learners rather than bringing learners to the schoolhouse.



←————→
2 sigma

Technology– Instruction is Effective



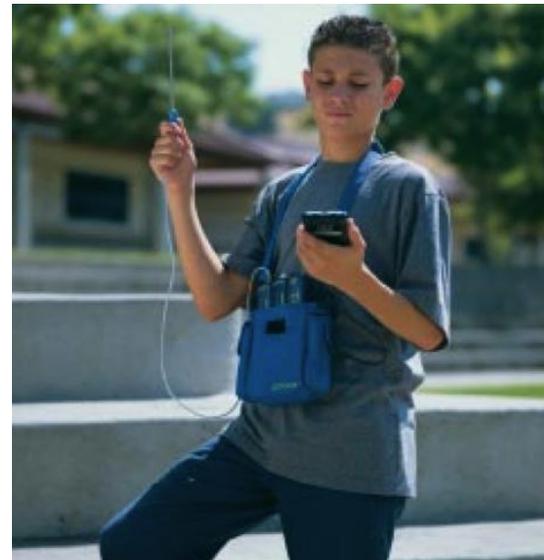
Some effect sizes for studies comparing Intelligent Tutors-
with more conventional technology-based instruction

Active and Interactive

Active students using interactive learning objects on personal learning devices.

Objects will be intelligent, tailored to the needs, states and traits of individuals or group (battalion, crew) and based on natural language dialogue.

Personal devices, will be portable, be easy to use, have with high bandwidth.



Agenda

→ Past: Student, domain and tutoring knowledge

Current Intelligent Tutoring Systems

Future Intelligent Tutoring Systems

Discussion and Further Work

Past Intelligent Tutors

Definition of Intelligent Tutors

- Generative – generate appropriate problems, hints and help.
- Student modeling – assess the current state of the student's knowledge
- Expert modeling – assess and model expert performance
- Teaching modeling—manage the teaching.
- Self-Improving – monitor, evaluate and improve its own teaching as a result of experience.

Main Drivers for this Change in Education

- ❄ Artificial intelligence (AI) leads to personalized training by modeling domain, student, tutoring and communication knowledge.
- ❄ Cognitive science leads to a deeper understanding of how people think, solve problems and learn; and
- ❄ The Web provides an unlimited source of information, available anytime and anyplace.



Intelligent Tutors Do Improve Learning

- Nearly the same improvement as one-on-one human tutoring.
- Effectively reduce by one-third to one-half the time required for learning.
- Networked versions reduce the need for training support personnel by about 70% and operating costs by about 92%.

Definition: Intelligent Tutoring Systems

- Student Knowledge
- Domain Knowledge
- Tutoring Knowledge
- Communication Knowledge

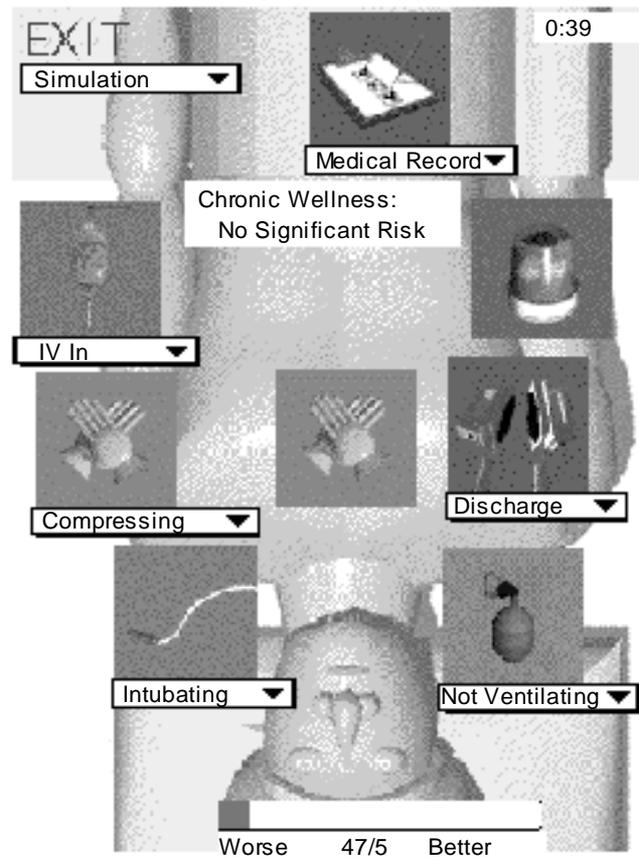
The Variety of Knowledge Represented in a Student Model

Knowledge	What is Represented?
<p style="text-align: center;">Topics</p>	<p>Concepts, facts, procedures: Rules and steps explicitly identified. Skills: ability on skills, goal, plans and tasks. Declarative Knowledge expressed as facts about objects, events and their relations.</p>
<p style="text-align: center;">Misconceptions</p>	<p>Well-understood errors; Bug Library. The <i>student model</i> represents incorrect “buggy” knowledge in addition to missing knowledge .</p>
<p style="text-align: center;">Learning Characteristics</p>	<p>Learning rate, student preferences, habits and profile; type of thinking (Inductive, deductive). Degree of concentration (typing errors)</p>
<p style="text-align: center;">Affective Characteristics</p>	<p>Engagement, challenge, boredom, seriousness, level of concentration</p>
<p style="text-align: center;">Student Experience</p>	<p>User history, student attitude toward some statement; discourse, plans, goals, task experience, context of the user</p>
<p style="text-align: center;">Stereotypes</p>	<p>General knowledge of student’s ability and characteristics; Initial model of student.</p>

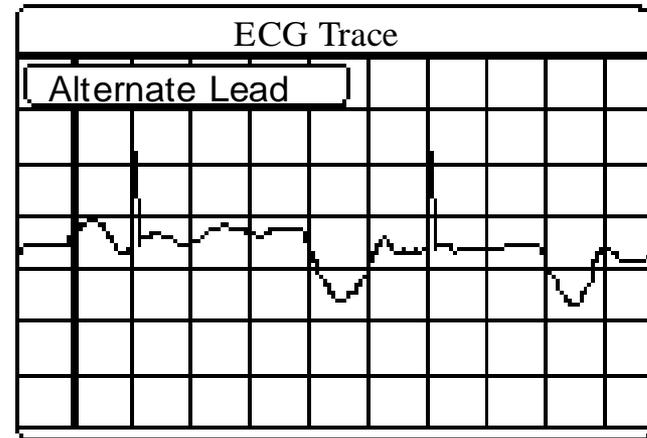
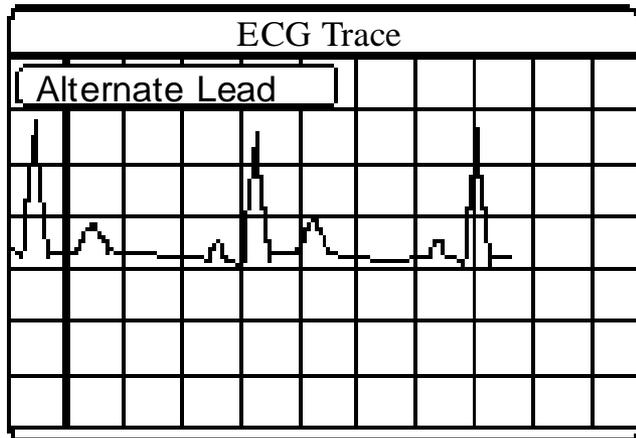
The Simulated Patient

Cardiac Resuscitation

[Eliot, 1994]



Simulated ECG Traces



Definition: Intelligent Tutoring Systems

Student Knowledge

→ Domain Knowledge

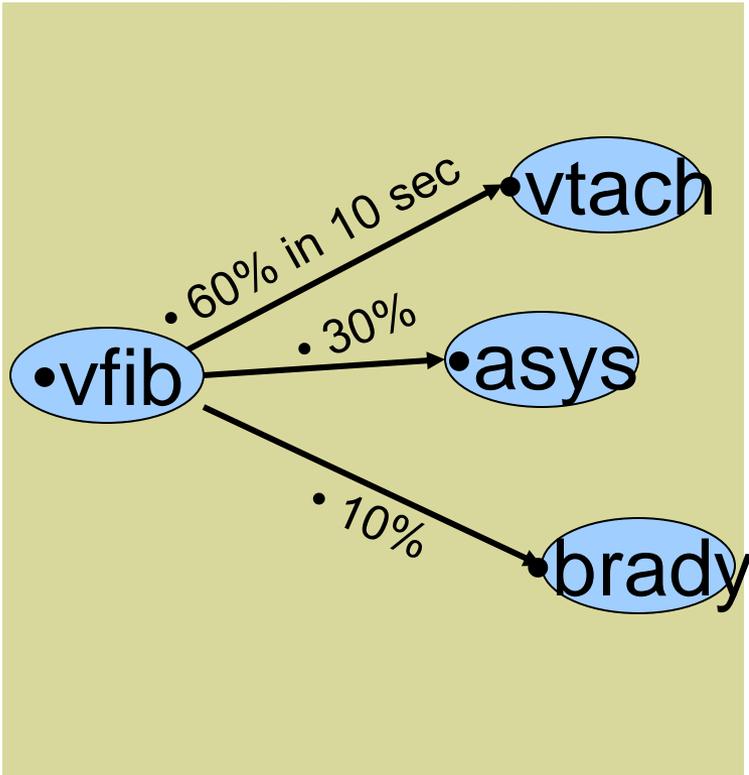
Tutoring Knowledge

Communication Knowledge

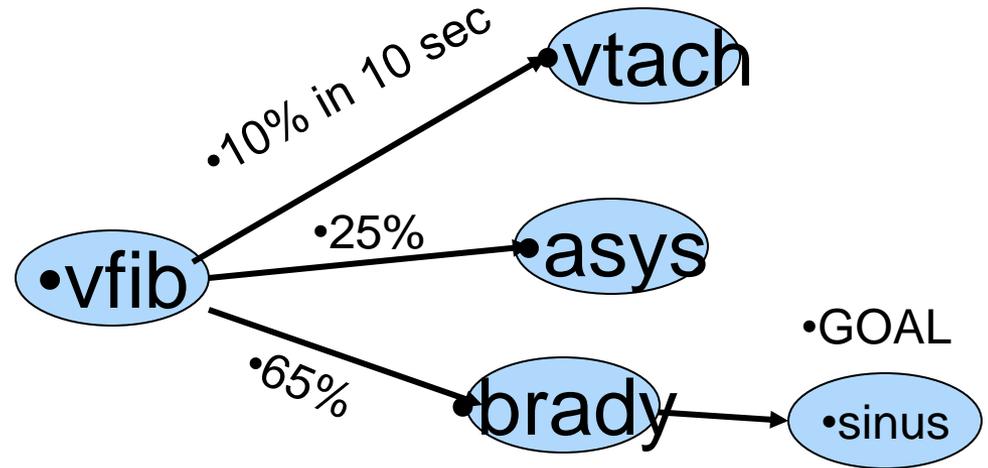
Student Model

Cardiac Resuscitation
[Eliot, 1994]

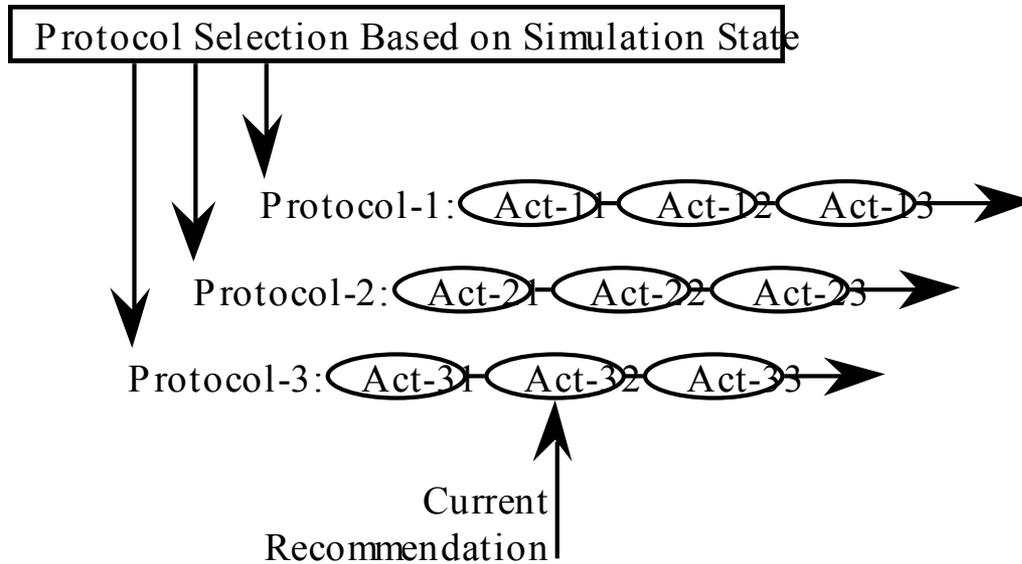
Domain Model



Domain Model
Biased to reach goal state



Protocol Recognition



Model-tracing Tutors

- Contain a cognitive model or simulation of an expert's correct thinking in the domain.
 - The cognitive model is capable of correctly solving any problem assigned to the student.
 - The students' actions are compared to those of the expert and if their actions diverge sufficiently, the tutor offers advice or feedback.
 - The tutor keeps track of trainee actions, such as making selections from a menu or drawing on graphical user interface.
 - Advantage is that when a trainee is lost the model tracing tutor offered advice within the context of the problem.

Definition: Intelligent Tutoring Systems

Student Knowledge

Domain Knowledge

→ Tutoring Knowledge

Communication Knowledge

What is tutoring knowledge?

An intelligent tutor uses a variety of objects (examples, explanations) to tutor the student.



Tutoring Components

Tutoring Components	Examples
Objects	Explanation, example, hint, counter example, quiz, question, display, analog
Actions	Test, summarize, describe, define, interrupt, demonstrate, implication, application, teach procedure.
Tasks	Teach step by step, ask student, move on, stay here, go back to topic.

Representing Teaching Knowledge

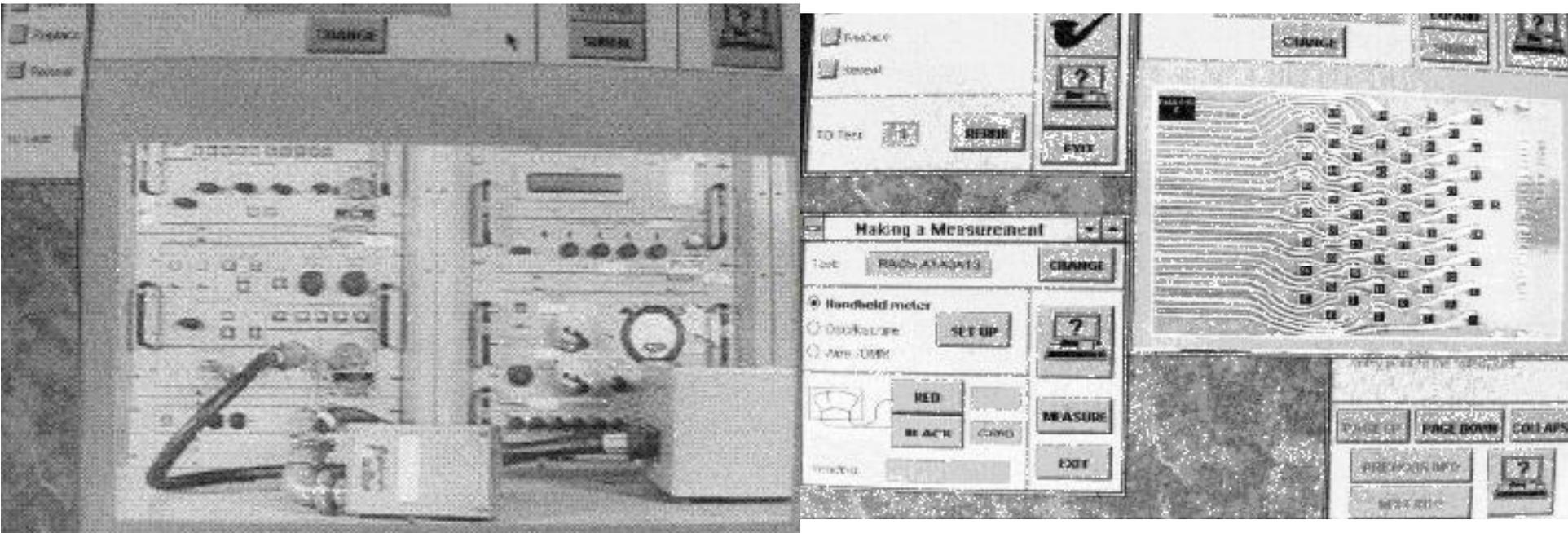
Classes of Tutoring Strategies	Automated System
Human teaching	Apprenticeship learning Problem-solving/ handling errors Bug-based tutoring Tutorial dialogue Case-based reasoning Collaborative learning
Learning theory	Model-tracing/cognitive tutors Constructivist theory Situated Learning The Zone of Proximal Development Self-explanation Socratic Learning
Facilitated by technology	Animated Pedagogical Agents Virtual Reality Interactive Simulations and Illustrations

Considerations Made by the Tutor

About	Examples
Student Personality	Motivation: high to low Learning ability: independent to passive
Knowledge Domain	Knowledge-setting: contextualized to isolate; connected to disassociated. Knowledge type: Facts, ideas or theory
Teaching Intervention	A continuum from intrusive to non intrusive; active to passive
Task Type	Theory type: Case based (e.g., math); Understanding: (e.g., gravity) Problem Solving; cognitive skill consisting of units of goal- related knowledge.

Apprenticeship

Lajoie and Lesgold, 1992; Sherlock



SHERLOCK

- Computer-based coached practice environment driven by a dynamic trainee model.
 - Used by Air Force trainees (F-15 manual avionics technicians) to learn difficult skills of troubleshooting the electronic equipment they use to make diagnoses in faulty devices.
 - *Test station*

Cognitive Apprenticeship behind SHERLOCK

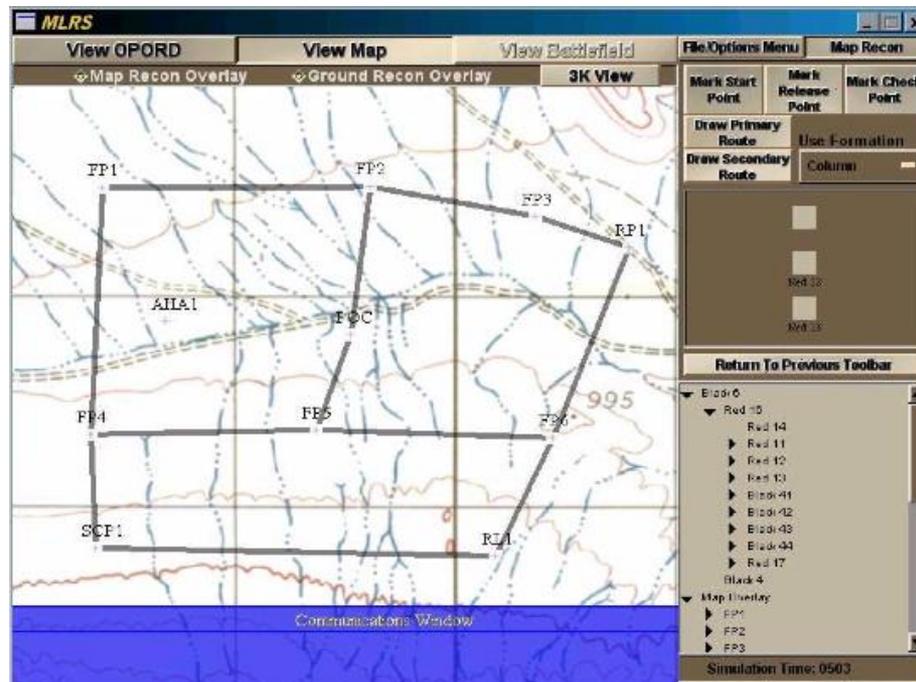
- Learning is situated in a social context similar to those in which the skills will be used
- Both novice and master are active participants in the learning environment
- Cognitive processes are externalized and displayed for inspection

Cognitive Apprenticeship behind Sherlock (2)

- Modeling, coaching and fading are essential.
- Learners perform with support (coaching) that is gradually withdrawn (fading).
 - Explicit models of student competence is used to drive coaching and fading.
 - Coaching is individualized by giving different levels of help according to the student's current state of achievement.

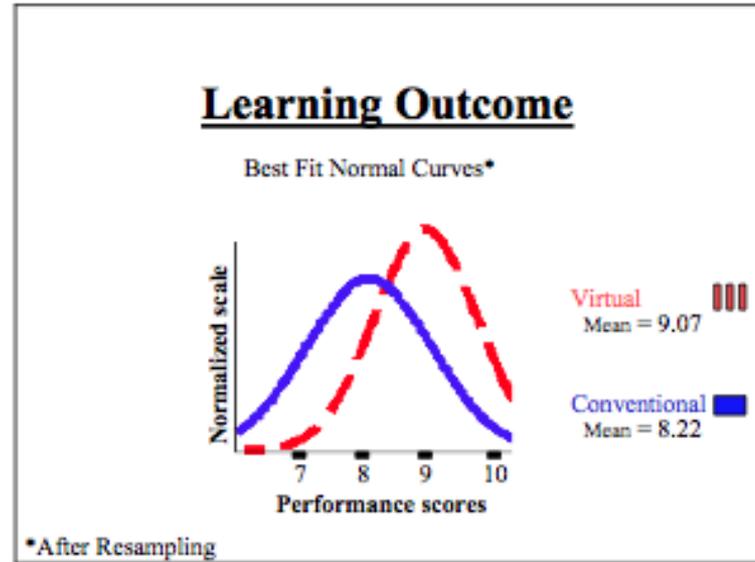
The Virtual Sand Table: Intelligent Tutoring for Field Artillery

Wisher, Macpherson (ARI), L. Jared Abramson and David M. Thornton (GMU), and James J. Dees (U.S. Army Training and Doctrine Command).



Students deployed multiple launch rocket system assets during a reconnaissance and selection of position task. Two-dimensional view with one student's solution to the problem of emplacing a Company in a 3 km area of the National Training Center.

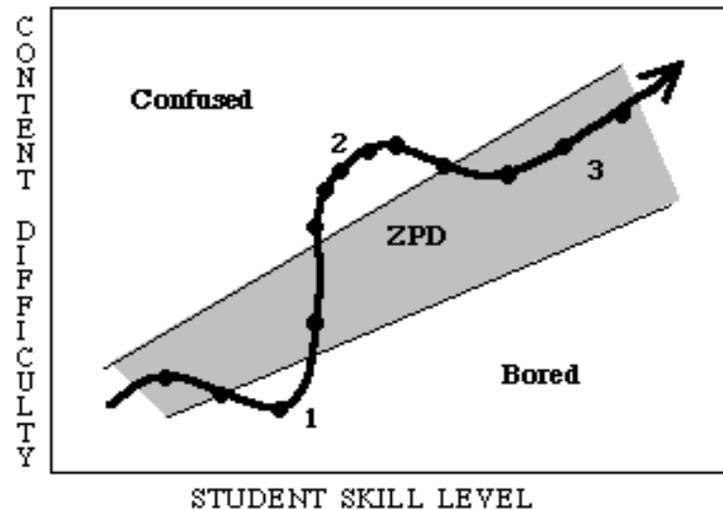
RESULTS Sandbox Tutor.



The tutor replicated the training with the added advantage of informative feedback and computer-based coaching during the exercise. Results, as measured by a hands-on performance test, indicated superior performance by the Virtual Sand Table treatment group, with an effect size of just over one standard deviation.

The Zone of Proximal Development

- The distance between the development level and the potential development with adult or peer guidance.
 - a trainee can perform a task with guidance or with the help of a peer that could not be achieved by his/herself.
- Vygotsky believed that what a person can perform today with assistance he will be able to perform tomorrow independently.



Definition: Intelligent Tutoring Systems

Student Knowledge

Domain Knowledge

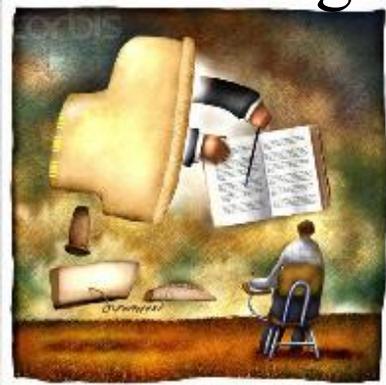
Tutoring Knowledge

→ Communication Knowledge

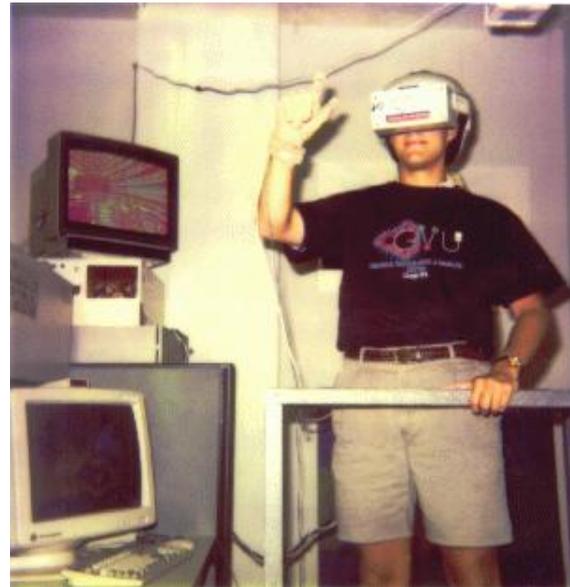
Communication Knowledge

Modes, methods and technology to support trainee interaction.

- React to the student's work;
- Demonstrate that the student's thinking can be followed;
- Reassure the trainee that he/she has reached the right conclusion for the right reason.

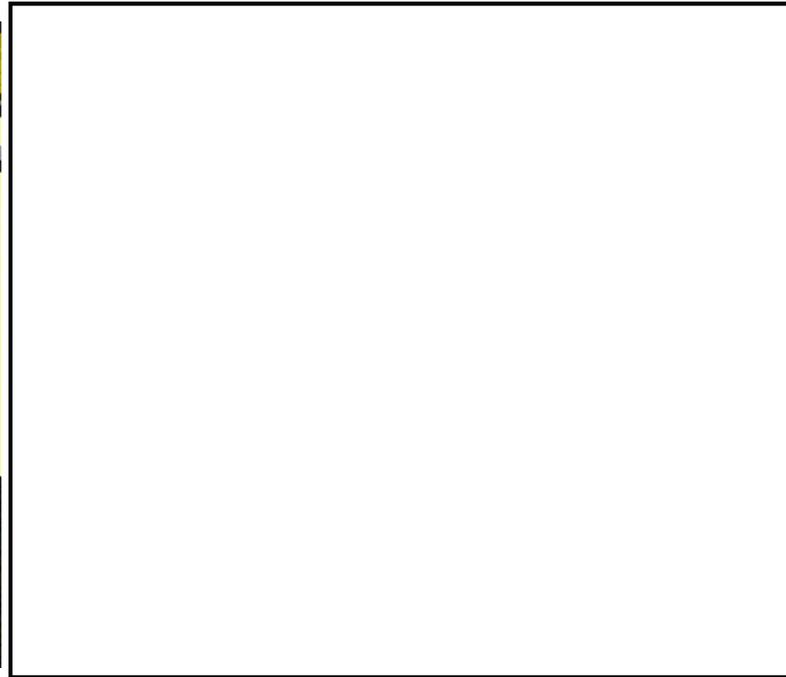
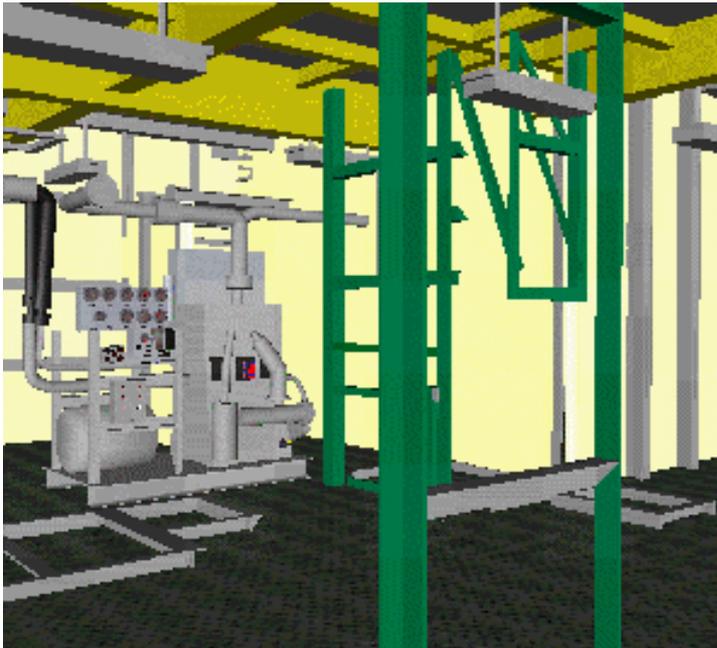


Virtual reality environments



Virtual reality environments typically consist of head-mounted displays and data glove worn by the person on the right. (a) ISI, University of Southern California, Project VET; (b) Virtual Reality Exposure Therapy, Georgia Tech, USA.

Training for a gas turbine propulsion system (left) aboard US Navy surface ships



The tutor places trainees in the space and points to the high-pressure air compressor (HPAC), part of the propulsion system (left).

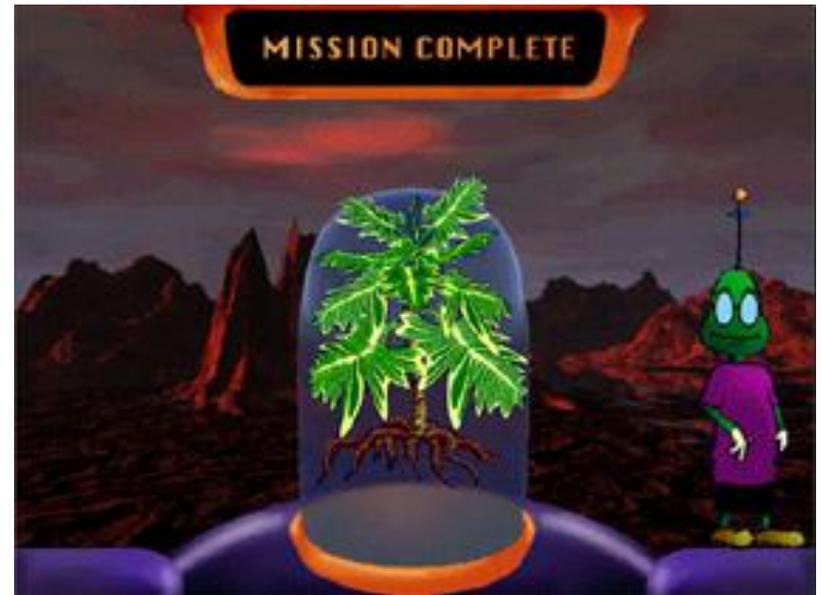
STEVE, Lewis Johnson, ISI, CARTE

Team training in virtual reality



STEVE was assigned a role within an overall task to monitor another agent.

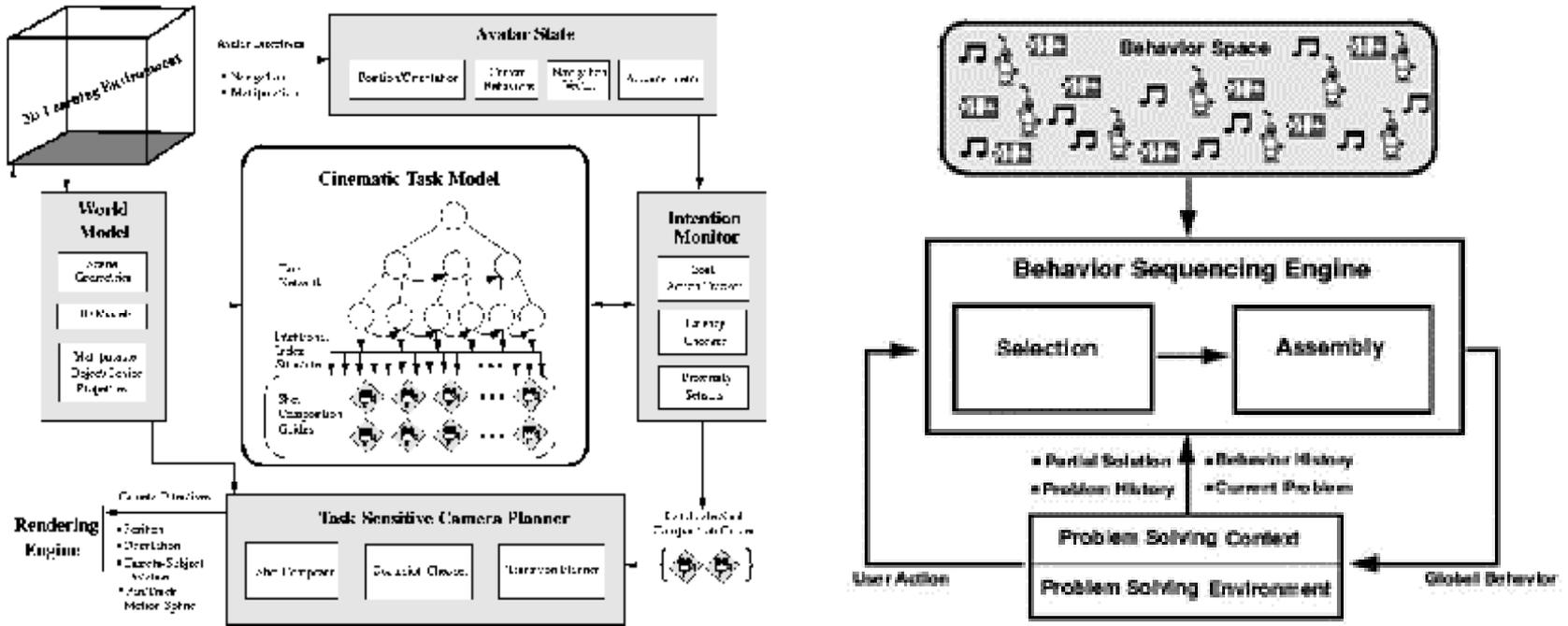
Herman



Herman was a *pedagogical agent* in Design-A-Plant.

Herman watched as students selected the appropriate roots for a plant in an Alpine meadow (left). Then Herman congratulated the student on a correct plant design (right).

Herman (2)



Design-A-Plant agent behavior

Information on How to Build Intelligent Tutors

Student Knowledge

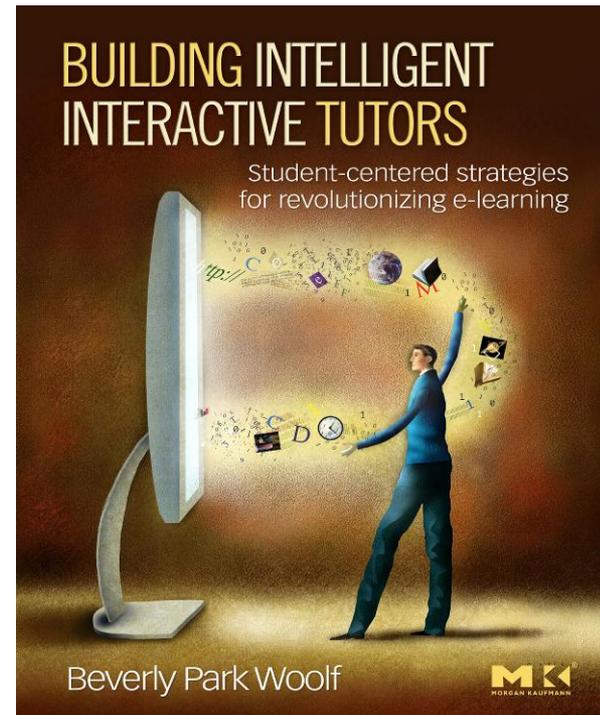
Domain Knowledge

Tutoring Knowledge

Communication Knowledge



Shameless Plug



Agenda

Past: Student, domain and tutoring knowledge

→ Current Intelligent Tutoring Systems

Future Intelligent Tutoring Systems

Discussion and Further Work

Current Intelligent Tutors

Success stories

Cognitive Tutors (algebra)

Adaptive scaffolding on algebra problems

More than 500,000 students per year, middle and high schools. Effect sizes: 1.2 and 0.7 on experimenter-designed tests; 0.3 on standardized tests.

25% more students pass state standardized exams; 70% greater likelihood of completing subsequent mathematics courses;

ANDES (physics)

Personalized help on 500 online physics homework problems.

More than 700 students. Effect sizes: 0.52 (non-science students); 0.223 (engineers); 1.21 (using diagrams); 0.69 (using variables).

9.8 - 12.9% increase in grades on hour-long exams, $p = 0.0001-0.03$.

Replaces grading homework; Manipulated only the way students do their homework.

Current Intelligent Tutors (2)

Success stories

Wayang (mathematics)

Adaptive help and multimedia for 300 math problems.

More than 3,000 middle and high school students. Evaluations measures impact of support, problem difficulty and digital character on student performance.

10-16% more students pass state exams. Increased confidence and reduced frustration. System infers student emotion with 86.36% agreement with what students report.

Project Listen (reading)

Student reads passages aloud; system identifies words in context.

More than 3,000 students. Effect sizes range up to 1.3; 0.63 for passage comprehension. Differences in oral reading fluency (words read correctly per minute).

Students outgained control group in word comprehension (e.g., effect sizes of 0.56), passage comprehension, phonemic awareness, word identification, passage comprehension, and spelling.

Current Intelligent Tutors (3)

Success stories

ASSISTments (mathematics)

61,233 homework questions plus feedback

Randomized controlled tests; log data.

1500 users every day. In sum, 7500 students and 100 teachers, spanning 25 districts in Massachusetts and 12 districts in Maine. Effect size of 0.6.

Students improve half a standard deviation.

Crystal Island (microbiology)

Intelligent 3D game-based environments.

1450 students in grades 5 and 8.

Significant learning gains (about 2-2.5 question increase). Student learning and problem solving performance predicted by presence questionnaire.

Games motivate inquiry-based science learning with pedagogical agents; students use systems for a single, one-hour session; not yet part of everyday classrooms.



BILAT, Interview, A Military Simulation

Institute of Creative Technology,
University of Southern California



Contains:

Domain Knowledge;

how to improve market,
local law enforcement,
maintain power grid, etc.

Student Model

Performance, skills,

Communication Knowledge

Computer graphics,
gaming technology,
40,000 lines of dialogue
for virtual characters

BILAT, Interview, A Military Simulation

Institute of Creative Technology,
University of Southern California

The screenshot displays the BILAT simulation interface, which is overlaid on a 3D-rendered office environment. The interface is divided into several functional areas:

- MEETINGPARTNER:** Shows a profile for 'Farid' with a 'TRUST' level of 0.
- OBJECTIVE:** Lists 'Learn why market is not being used' and 'Get Police Cooperation'.
- PREPARATION:** A central menu with tabs for 'OBJECTIVE REVIEW', 'MEETING PARTNER', 'INTENDED OUTCOME', 'RESEARCH', 'PREP SHEET', and 'REQUISITIONS'. The 'PREP SHEET' tab is currently active.
- REHEARSAL:** Includes a 'REHEARSAL' button.
- MEETING:** Includes buttons for 'MEETING' and 'NEGOTIATION'.
- AAR:** Includes buttons for 'AAR' and 'FOLLOW-UP'.
- TIME:** Displays '3 D 22:20'.
- Help, Options, Info:** A row of utility buttons.
- Prep Sheet Checklist:** A large table with various sections for planning the meeting, each with a question mark icon for help.

CONTACT	DTG:	COPY 1 OF 1
DESIRED ENDSTATE	OPENING COMMENTS:	
IO Themes and Messages: The U.S. is firmly committed to... The U.S. created this market to...	Talking Points	The market was part of a U.S.... The U.S. suspects insurgents are... The U.S. believes that the...
Wanted Outcomes	My Bottom Line	
Partner's Intended Outcome	Partner's Bottom Line	
Possible Impressions: Farid feels that the U.S. does not... Farid believes the U.S. to be... Farid is upset because Ali's...	Impression Strategy	Demonstrate that the U.S. has the... Assure Farid that the U.S. wil... Assure Farid that the U.S. wil...
Possible Other Partner Issues	Partner Issue Strategy	
Order Of Events	Relationship Building Topics	Exit Strategy
- Background:** A 3D office scene with a desk, laptop, printer, and a large monitor displaying a map. A tooltip reads: 'Please select an area in the Prep Sheet that you would like to prepare.'

BILAT, Interview, A Military Simulation

Institute of Creative Technology,
University of Southern California

MEETING PARTNER	OBJECTIVE	PREPARATION					REHEARSAL	MEETING		AAR		
Fard TRUST -3	Learn why market is not being used Get Police Cooperation	OBJECTIVE REVIEW	MEETING PARTNER	INTENDED OUTCOME	RESEARCH	PREP SHEET	REQUISITIONS	REHEARSAL	MEETING	NEGOTIATION	AAR	FOLLOW-UP
		TIME 3 D 23:10					Help		Options		Info	

You did a good job on relationship building and sending the right messages. However, threats and intimidation only hurt your position.

SCORE RANGE	
0% - 40%	RED
41% - 80%	AMBER
81% - 100%	GREEN

	"Small Talk"	"Negotiate"	"End Meeting"	"Use Interpersonal Skills"
SUMMARY	89%	33%	60%	0%

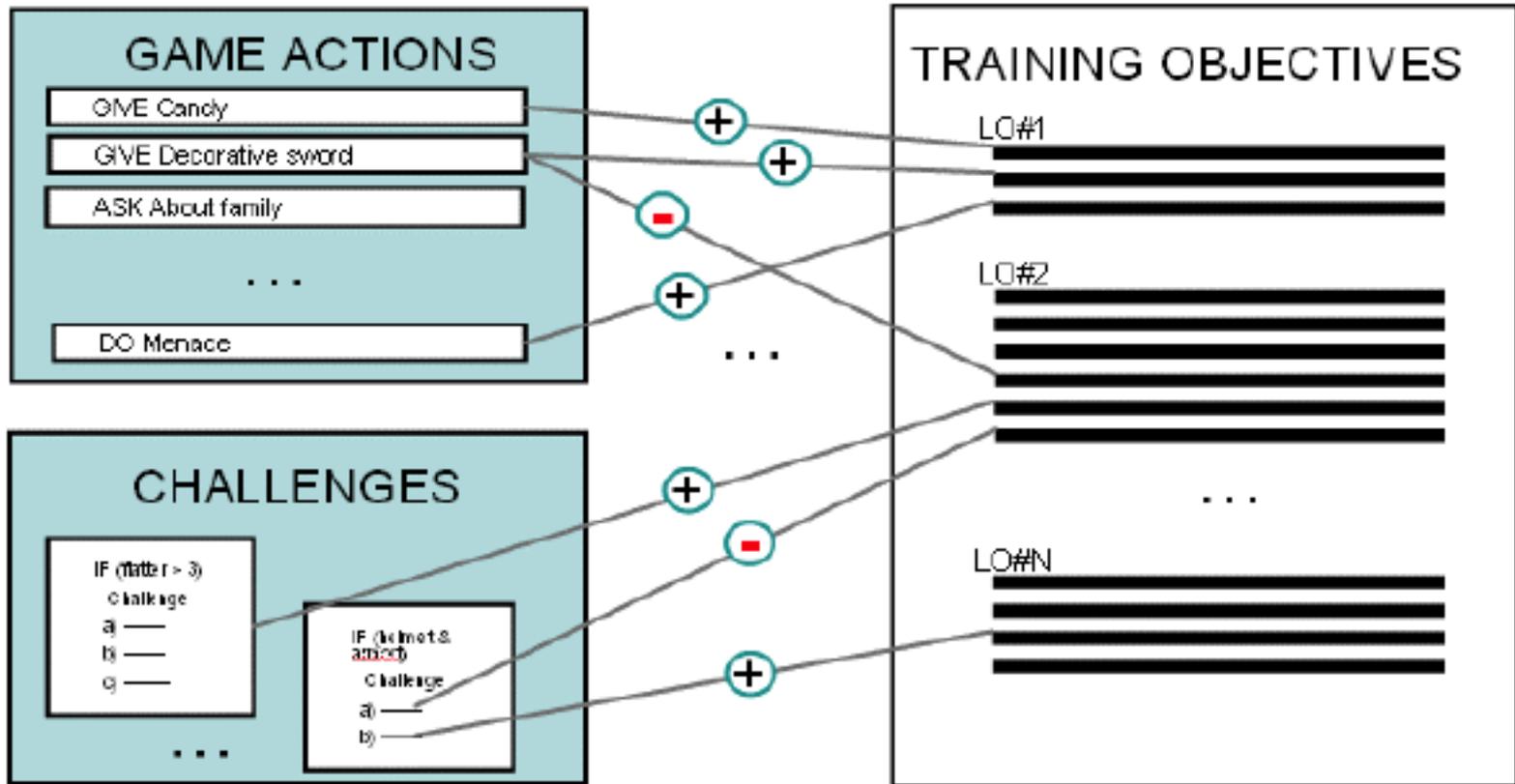
ACTIONS	TIME	PERFORMANCE
"Remove Keelal"	0:00	correct
"Remove helmet and sunglasses"	0:02	correct
"Greet in Arabic"	0:04	correct
"Show photograph of wife"	0:06	incorrect
"Show photograph of husband"	0:09	correct
"Talk to Fard about the community's problems"	0:11	correct
"Compliment Fard on his leadership qualities"	0:13	correct
"Talk about your family"	0:15	correct
"Demand compliance in finding insurgents"	0:18	incorrect
"Compliment locals"	0:20	correct
"Ask Fard why the people are upset about the market"	0:22	mixed
"NEGOTIATION"	0:24	incorrect

ACTIONS	TIME	PERFORMANCE
"Give Fard a gift of body armor in order to demonstrate goodwill"	0:26	correct
"Excuse self politely"	0:28	mixed

Next

BILAT, Interview, A Military Simulation
Institute of Creative Technology,
University of Southern California

Training Knowledge



Helicopter Pilot

US Army and ARI, Stottler Henke



Motivation:

Most flight simulations require the presence of a human trainer;
An adaptive tutor is needed to reason about the pilot and solution.

Solution:

The student model considers the pilot's performance history, past training, patterns of performance, personality traits and learning style
The system diagnoses student errors and provides appropriate feedback
It encodes instructional goals, instructional planning and agents.

Helicopter Pilot Training Stottler- Hinkley



High-Level Command

ARI, Stottler Henke



Student	Who: Delta Company Role: ReserveForce Where: south of wharton hill Route: eastern road and south of wharton hill
Tutor	Roger. Anything further?
Student	Done
Prompt	
Tutor:	Alright. Let's move on.
Tutor:	We're going to discuss this situation and what you've proposed to do about it.
Tutor:	Let's start by talking about the red forces and their situation.
Tutor:	What sort of force do you think you're facing in your area east of the river?

Motivation:

Tactical skills can not be taught as methods or procedures
Trainees need extensive practice and to prioritize goals

Solution:

System provides a variety of tactical situations (ARI vignettes)
along with Socratic questioning, hints and feedback
System evaluates each student's reasoning by comparing
solutions and rationale with that of expert response.

Tactical Action Officer

US Navy, Stottler Henke

Motivation:

Tactical training typically requires 1 instructor per 2 trainees.
Team members evaluate, coach and debrief other trainees
The goal is to reduce the number of instructors needed.

Solution:

Computer agent plays team member allowing students to practice concepts and principles.
Speech-enabled graphic user interface supports dialogue; Soldiers converse with simulated team member to issue commands
Automatic evaluation of trainee; System infers tactical principles used by students.

Serious games

Mental contests, played with a computer in accordance with specific rules, that uses entertainment to further training and education.

Mike Zyda, IEEE Computer 38 (9), 2005
“From Visual Simulation to Virtual Reality to Games”

Crystal Island



- Teaches 8th grade microbiology
- Discover the source of an infectious disease plaguing island
- Narrative Learning Environment - facilitate students' semantic encoding of new information and making commitments to long-term memory in the form of episodic memories
- Dynamic decision network (DDN) guides narrative
- Inquiry-based learning

Narrative planning



- Agent builds narrative elements based upon *narrative objectives*, *storyworld state*, and *student state*.

- Look at Bayesian network and n-gram models for learning students' goals based upon their actions, to determine if sufficient "plot progress" has been made.

- Tutorial planner used to encourage *question formation*, *hypothesis generation*, *data collection*, and *hypothesis testing*.



[movie](#)

Blitz Game Studio's *Triage Trainer*



Controlled trials in UK found Triage Trainer “to be statistically significantly better at developing accuracy in prioritising casualties and in supporting students to follow the correct protocol to make their decision” -- TruSim website

Agenda

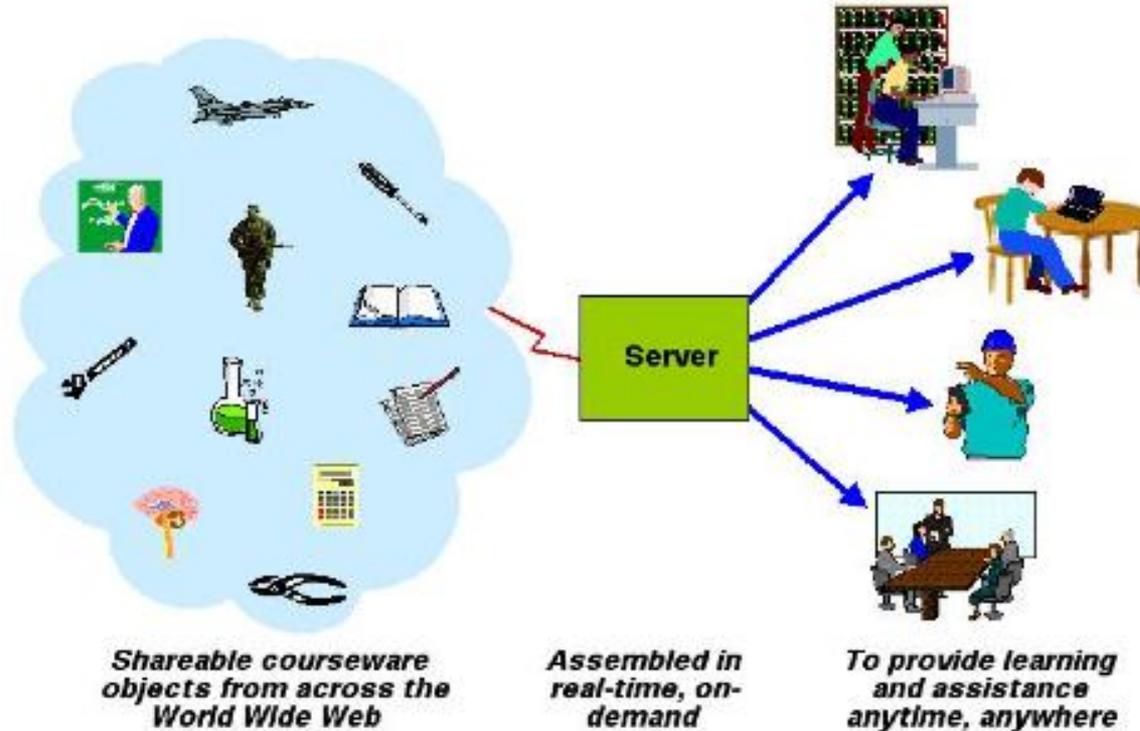
Past: Student, domain and tutoring knowledge

Current Intelligent Tutoring Systems

→ Future Intelligent Tutoring Systems

Discussion and Further Work

VISION (once again)



Global learning repository.
The big need is for intelligent, instructional content.